©Operative Dentistry, 2020, **45-6**, 655-663

Effect of Layering Techniques on Polymerization Shrinkage Stress of High- and Low-viscosity Bulk-fill Resins

A Tsujimoto • CA Jurado • WW Barkmeier • ME Sayed
T Takamizawa • MA Latta • M Miyazaki • F Garcia-Godoy

Clinical Relevance

The use of layering techniques is still advisable with many bulk-fill resins and should be the default unless a particular resin is known to not need it.

SUMMARY

Objective: The purpose of this study was to investigate how layering techniques affect polymerization shrinkage stresses of high- and low-viscosity bulk-fill resins.

Method: Six high-viscosity and six low-viscosity bulk-fill resins were evaluated. Aluminum blocks with a mesial-occlusal-distal (MOD) cavity were machined and randomly divided into groups for different filling techniques (bulk-fill vs horizontal layering vs oblique layering) and further subdivided according to type of resin (high- vs low-viscosity). The cuspal deflection resulting from the polymerization of bulk-fill resin bonded to a MOD cavity within an aluminum block was measured with a digimatic micrometer. Scanning electron microscopy analyses of tested resins were also conducted.

Results: In the high-viscosity bulk-fill resins, cuspal deflection of the MOD cavity ranged from 11.2 to 18.2 μm with the bulk-filling technique, from 10.7 to 15.5 μm with the horizontal layering technique, and from 10.9 to 15.2 μm with the oblique layering technique. In the

*Akimasa Tsujimoto, DDS, PhD, Operative Dentistry, Nihon University School of Dentistry, Tokyo, Japan

Carlos A Jurado, DDS, MS, Clinical Digital Dentistry, A.T. Still University Arizona School of Dentistry and Oral Health, Mesa, AZ, USA

Wayne W Barkmeier, DDS, MS, General Dentistry, Creighton University School of Dentistry, Omaha, NE, USA

Mohammed E Sayed, BDS, MDS, FRCDC, FACP, AFAAID, PhD, Prosthodontics, Jazan University College of Dentistry, Jazan, Saudi Arabia

Toshiki Takamizawa, DDS. PhD, Operative Dentistry, Nihon University School of Dentistry, Tokyo, Japan

Mark A Latta, DMD, MS, General Dentistry, Creighton University School of Dentistry, Omaha, NE, USA

Masashi Miyazaki, DDS, PhD, Operative Dentistry, Nihon University School of Dentistry, Tokyo, Japan

Franklin Garcia-Godoy, DDS, MS, PhD, PhD, Bioscience Research, University of Tennessee Health Science Center College of Dentistry, Memphis, TN, USA

*Corresponding author: 1-8-13, Kanda-surugadai, Chiyoda-ku, Tokyo, 101-8310, Japan; e-mail: tsujimoto.akimasa@nihon-u.ac.jp

https://doi.org/10.2341/19-217-L

low-viscosity bulk-fill resins, cuspal deflection of the material ranged from 9.2 to 19.8 μm with the bulk-filling technique, from 8.2 to 15.7 μm with the horizontal layering technique, and from 8.4 to 16.4 μm with the oblique layering technique.

Conclusion: Cuspal deflections for some high- and low-viscosity bulk-fill resins were significantly reduced by using layering techniques, but the resultant improvement of layering techniques was not applicable to all the bulk-fill resins used in this study.

INTRODUCTION

Restorative procedures using composite resin have become an essential part of daily practice because of material enhancements[1] and improvements in adhesive systems.[2] Material improvements over the years have resulted in an increase in patient demands for esthetics[3] and more emphasis on preserving tooth structure.[4] The wear resistance of composite resins has continued to improve, since their introduction as restorative materials, enabling expanded use in posterior restorations of large cavities with long-term durability.[5] A systematic review[6] comparing direct and indirect composite resin restorations in posterior teeth showed that there was no difference in longevity between direct and indirect restorations, regardless of the type of composite resin. In addition, a recent 20-year clinical study[7] of direct composite resin restorations in posterior teeth showed a high success rate and increased mean survival time.

However, polymerization shrinkage and its associated stress have remained a major concern of direct resin restorations, especially in large cavities in posterior teeth.[8] Numerous studies have been performed to assess polymerization shrinkage and stress development in composite resins.[9,10] Polymerization shrinkage causes stress at the interface between a tooth and a restoration as the elastic modulus of the resin increases during polymerization.[11] This stress may result in marginal gap formation, microleakage, and enamel micro-cracks and can give rise to pulpal irritation, secondary caries due to bacterial infiltration, and postoperative sensitivity, which in turn can lead to restoration failure requiring restoration replacement (Figure 1).[12] Efforts have been made to reduce polymerization shrinkage and stress by increasing inorganic filler loading,[13] modifying filler particle size and shape,[14] and developing new types of resin matrices.[15]

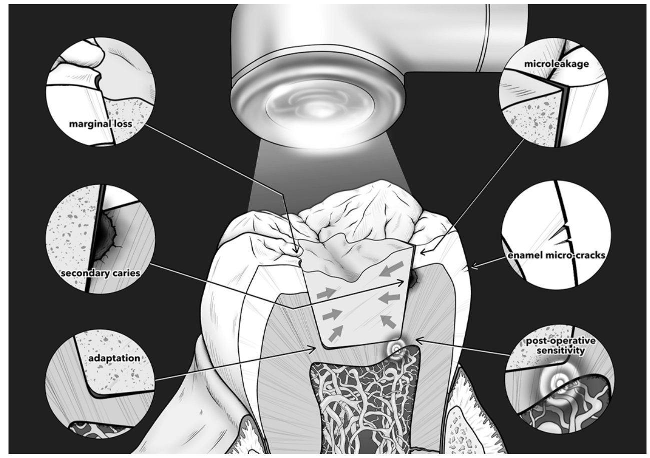

Figure 1. *Schematic drawing of the influence of polymerization shrinkage stress.*

However, increases in inorganic filler loading and modification of filler size and shape are limited by the need for a physicochemical combination within the resin matrix. Polymerization shrinkage and stress of composite resins can also be reduced by decreasing the reactive sites per unit volume through increasing the molecular weight per reactive group.[16] Nevertheless, this strategy also has its limitations because the use of monomers with a high molecular weight may produce increased viscosity, resulting in poorer handling characteristics, and potentially reducing mechanical strength. In addition, attempts to develop composite resins with completely new resin matrices that shrink considerably less, have been ongoing. Recently, a composite resin with a silorane resin matrix containing siloxane and oxirane was introduced, but this resin needs special adhesive systems for bonding.[17]

Clinical strategies to minimize the shrinkage stress of composite resins, such as horizontal and oblique layering techniques to decrease the C-factor, are still widely used.[18] In addition, recent developments have led to the introduction of high- and low-viscosity bulk-fill resins that can be used for large cavities with the bulk-fill technique.[19] These materials are designed to be used for placing the resin in increments of up to 4 mm, and one of their central characteristics is a much greater depth of cure than that found in conventional resins.[20] However, they have also been designed to reduce polymerization shrinkage stress to support their use in bulk-fill techniques.[5] No independent research has yet investigated whether the filling techniques used to reduce polymerization shrinkage stress are still necessary or valuable with these newly developed bulk-fill resins.

Although measurement of cuspal deflection is a useful way to evaluate the polymerization shrinkage stress of composite resins, the use of extracted teeth to measure cuspal deflection can produce significant discrepancies among specimens due to the lack of standardization of the anatomical and histochemical characteristics of the individual teeth.[21] Recently, Tsujimoto and others[5] fabricated aluminum blocks with identical shapes and dimensions instead of using extracted human teeth to examine cuspal deflection. The cuspal deflection of the aluminum blocks was measured using a digimatic micrometer or a confocal laser scanning microscope.

This laboratory study examined cuspal deflection of bulk-fill resins using standardized uniform aluminum blocks with mesial-occlusal-distal (MOD) cavity preparations. The purpose of this study was to investigate the influence of filling techniques on the polymerization shrinkage stresses of high- and low-viscosity bulk-fill resins. The null hypothesis was that the layering techniques would have no influence on the polymerization shrinkage stresses of high- and low-viscosity bulk-fill resins.

METHODS AND MATERIALS

Study Materials

Six high-viscosity bulk-fill resins were used: 1) Beautifil Bulk (BB, Shofu, Kyoto, Japan); 2) EverX Posterior (EP, GC, Tokyo, Japan); 3) Filtek Bulk Fill (FB, 3M OralCare, St Paul, MN, USA); 4) Quixx Fill Posterior Restorative (QF, Dentsply Sirona, York, PA, USA); 5) Tetric Evo Ceram Bulk Fill (TEB, Ivoclar Vivadent, Schaan, Liechtenstein); and 6) Tetric N Ceram Bulk Fill (TNB, Ivoclar Vivadent). Six low-viscosity bulk-fill resins were used: 1) Beautifil Bulk Flow (BF, Shofu); 2) EverX Flow (EF, GC); 3) Filtek Fill and Core Flowable Restorative (FF, 3M Oral Care); 4) SDR Flow+ (SD, Dentsply Sirona); 5) Tetric Evo Flow Bulk Fill (TF, Ivoclar Vivadent), and 6) X-tra Base (XB, Voco GmbH, Cuxhaven, Germany).

Specimen Preparation

Aluminum blocks (10 [W] × 8 [L] × 15 [D] mm) with a simulated MOD cavity (4 [W] × 8 [L] × 4 [D] mm) were milled out using a computer-aided design/computer-aided manufacturing system, creating two remaining cusps. This structure simulated a large Class II cavity preparation in a premolar. The inside of the cavity was submitted to airborne-particle abrasion with 50 μm Al_2O_3 powder for 10 seconds to improve surface characteristics for bonding. Air pressure was set to 0.2 MPa, and the distance between the tip and aluminum surface was approximately 10 mm (Jet Blast II, J. Morita, Tokyo, Japan). A universal adhesive (Scotchbond Universal Adhesive, 3M Oral Care) was applied according to the manufacturer's instructions before placing the high- and low-viscosity bulk-fill resins. The adhesive was light-cured for 10 seconds at a standardized distance of 1 mm using a quartz–tungsten–halogen curing unit (OptiLux 501, Kerr, Orange, CA, USA). The power density (>700 mW/cm^2) of the curing unit was confirmed with a dental radiometer (Model 100, Kerr) before specimen preparation.

Measurement of Cuspal Deflection

The aluminum blocks were randomly divided into three groups for different filling techniques (bulk-fill vs horizontal layering vs oblique layering technique) and were further subdivided according to the type of composite resin (high- vs low-viscosity) (Figure 2).

Group 1 (Bulk-fill Technique)—High- or low-viscosity bulk-fill resin was placed in bulk and light-cured for 40 seconds for each of the three exposed surfaces. Cuspal deflection was measured from the difference in the distance between the center of the two remaining cusps before the placement of composite resin and 10 minutes after light curing using a high-accuracy submicron digimatic micrometer (MDH-25MB, Mitutoyo, Tokyo, Japan).

Group 2 (Horizontal Layering Technique)—High- or low-viscosity bulk-fill resin was placed in two separate horizontal increments (2 mm each). Each increment was light-cured for 40 seconds each to the three exposed surfaces to ensure that an identical curing time was maintained. Cuspal deflection was measured in the same manner as in group 1.

Group 3 (Oblique Layering Technique)—High- or low-viscosity bulk-fill resin was placed in three separate oblique increments. Each increment was light-cured for 40 seconds each to the three exposed surfaces to ensure that an identical curing time was maintained. Cuspal deflection was measured in the same manner as in group 1 and group 2.

Scanning Electron Microscopy (SEM) Observations

SEM (TM 3000, Hitachi-High Technology, Tokyo, Japan) was used to examine the filler size and shape of the tested high- and low-viscosity bulk-fill resins. A thin coating of gold-palladium alloy was applied in a sputter coater (SC7620 Mini Sputter Coater, Emitech, East Sussex, UK) to prevent electrostatic

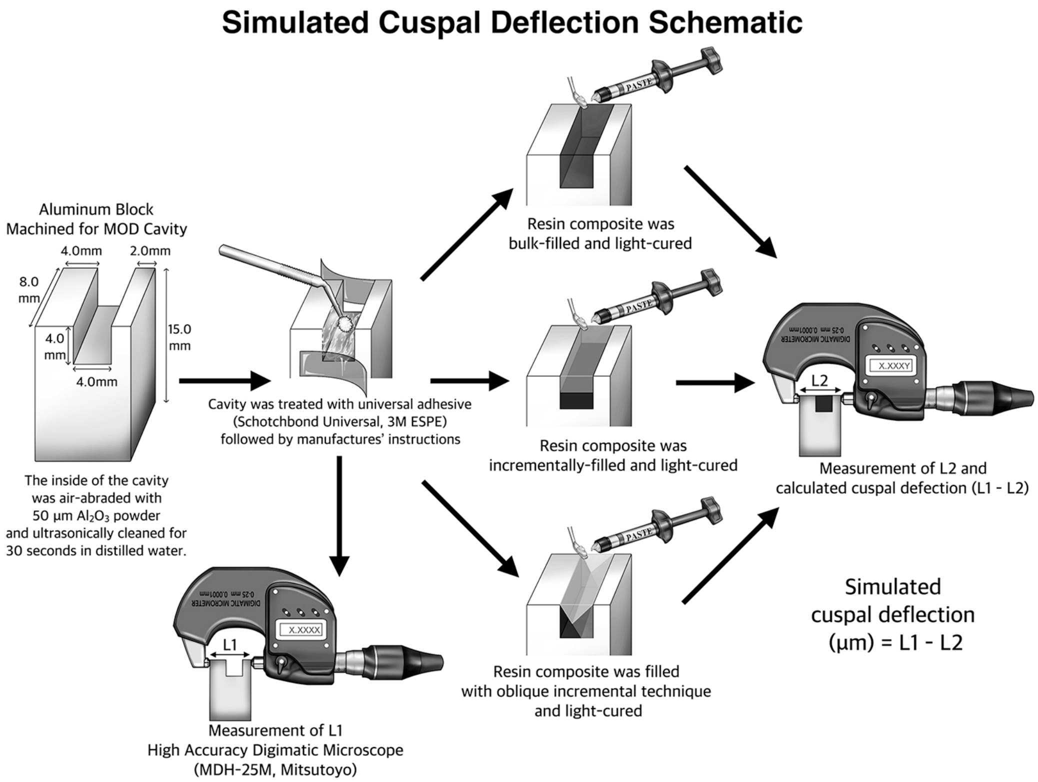

Figure 2. *Schematic drawing of the experimental set-up for simulated cuspal deflection of bulk-fill resins.*

charge from accumulating at the sample surface. The observations were done at an operating voltage of 15 kV.

Statistical Analysis

Statistical analysis was conducted with a commercial statistical software package (SPSS Statistics 25, IBM; Armonk, NY, USA). Two-way analysis of variance with a Tukey *post hoc* honest significant difference test was used to analyze the gathered data for the influence of 1) layering technique and 2) type of resin with an α level of 0.05.

RESULTS

Cuspal Deflection

The effect of layering techniques on polymerization shrinkage stresses is shown in Table 2 for high-viscosity bulk-fill resins and in Table 3 for low-viscosity bulk-fill resins. Cuspal deflection for the high-viscosity resins ranged from 11.2 to 18.2 µm with the bulk-fill technique, 10.7 to 15.5 µm with the horizontal layering technique, and 10.9 to 15.2 µm with the oblique layering technique. The rank order of cuspal deflection using the bulk-filling technique was TEB-FB-TNB-QF-EP-BB and that using the layering technique was TEB-EP-FB-TNB-QF-BB.

Cuspal deflection for the low-viscosity resins ranged from 9.2 to 19.8 µm with the bulk-fill technique, 8.2 to 15.7 µm with the horizontal layering technique and 8.4 to 16.4 with the oblique layering technique. The rank order of cuspal deflection using the bulk-filling technique was SD-FF-TF-EF-XB-BF and that using the layering techniques was SD-FF-EF-TF-XB-BF.

The cuspal deflection of BB, EP, and QF in high-viscosity resins and the cuspal deflection of BF, EF, and XB in low-viscosity resins were decreased when the layering techniques were used, unlike those of other resins.

SEM Observation

Representative SEM observations of tested resins are shown in Figure 3. The SEM images clearly show that there are differences in the size and shape of fillers in the high- and low-viscosity bulk-fill resins. BB, TEB, TNB, and QF among high-viscosity resins as well as BF, SD, TF, and XB among low-viscosity resins showed irregular particles with a broad size range (<1 to 20 µm). EP and EF showed short E glass fibers of different diameters and irregular

Table 1: *Composite Resins Used in This Study*

Material Type	Material (Code)	Matrix Resin Composition	Filler Composition	Manufacturer
High-viscosity bulk-fill resin	Beautifil Bulk (BB)	Bis-GMA, Bis-MPEPP, UDMA, TEGDMA	Fluoro-silicate glass	Shofu, Kyoto, Japan
	EverX Posterior (EP)	Bis-GMA, PMMA, TEGDMA	Short E-glass fiber filler, barium glass	GC, Tokyo, Japan
	Filtek Bulk Fill (FB)	Bis-EMA, Bis-GMA, TEGDMA	Silica filler, zirconia filler, zirconia/silica cluster filler	3M Oral Care, St Paul, MN, USA
	Quixx Fill Posterior Restorative (QF)	Bis-EMA, UDMA, TEGDMA	Strontium-aluminum-sodium-fluoridephosphate-silicate glass	Dentsply Sirona, York, PA, USA
	Tetric Evo Ceram Bulk Fill (TEB)	Bis-EMA, Bis-GMA, UDMA	Silanated barium glass filler	Ivoclar Vivadent, Schaan, Liechtenstein
	Tetric N Ceram Bulk Fill (TNB)	Bis-EMA, Bis-GMA, UDMA	Silanated barium glass filler	Ivoclar Vivadent
Low-viscosity bulk-fill resin	Beautifil Bulk Flowable (BF)	Bis-GMA, Bis-MPEPP, TEGDMA, UDMA	Fluoro-silicate glass	Shofu
	Ever X Flow (EF)	Bis-GMA, PMMA, TEGDMA	Short E-glass fiber filler, barium glass	GC
	Filtek Fill and Core Flow (FF)	Bis-GMA, UDMA	Silica filler, zirconia filler, zirconia/silica cluster filler	3M Oral Care
	SDR Flow+ (SD)	Bis-EMA, modified TEGDMA, UDMA	Barium-fluoro-alumino-silicate glass, strontium-fluoro-alumino-silicate glass	Dentsply Sirona
	Tetrik Evo Bulk Flow (TF)	Bis-EMA, Bis-GMA, UDMA	Silanated barium glass filler	Ivoclar Vivadent
	X-tra Base (XB)	Aliphatic dimethacrylate, Bis-EMA	Inorganic fillers	Voco GmbH, Cuxhaven, Germany

Abbreviations: Bis-EMA, bisphenol A diglycidyl methacrylate ethoxylated; Bis-GMA, bisphenol A diglycidyl methacrylate; Bis-MPEPP, 2,2-Bis(4-methacryloxypolyethoxyphenyl)propane; PMMA, polymethyl methacrylate; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate.

particles of a relatively uniform small size (<1 μm). The concentration of short E glass fibers in EF was higher than that in EP. FB and FF showed quite small (<1 to 5 μm) irregular, and spherical particles.

DISCUSSION

Cuspal deflection is one of the accepted indicators of polymerization shrinkage stress of composite resins and has been evaluated using devices such as linear variable differential transformers, direct current differential transformers, and strain gauges.[22] Recently, Tsujimoto and others[5] developed a cuspal deflection measurement technique using a digimatic micrometer. Compared with previously reported methods, the digimatic micrometer may be a more accessible and practical approach to measuring cuspal deflection than use of confocal scanning laser

Table 2: *Cuspal Deflection of High-viscosity Bulk-fill Resins*[a]

High-viscosity Bulk-fill Resin (Code)	Cuspal Deflection (μm)		
	Bulk-fill	Horizontal Layering	Oblique Layering
Beautifil Bulk (BB)	17.2 (0.6) aA	15.5 (0.8) aB	15.2 (0.7) aB
EverX Posterior (EP)	18.2 (0.8) aA	11.9 (0.9) bB	12.7 (0.8) bB
Filtek Bulk Fill (FB)	13.3 (0.9) bA	12.3 (0.9) bA	12.8 (0.8) bA
Quixx Fill Posterior Restorative (QF)	14.8 (0.5) cA	14.2 (0.6) cA	14.1 (0.6) cA
Tetric Evo Ceram Bulk Fill (TEB)	11.2 (0.6) dA	10.7 (0.7) dA	10.9 (0.6) dA
Tetric N Ceram Bulk Fill (TNB)	13.5 (0.9) bA	12.5 (1.2) bA	12.6 (1.1) bA

[a] *Values in parenthesis are standard deviations (n=10). The same lowercase letter in the same vertical column indicates no significant difference (p>0.05). The same uppercase letter within an individual row indicates no significant difference (p>0.05).*

Table 3: *Cuspal Deflection of Low-viscosity Bulk-fill Resins*[a]

Low-viscosity bulk-fill Resin (Code)	Cuspal Deflection (μm)		
	Bulk-fill	Horizontal Layering	Oblique Layering
Beautifil Bulk Flow (BF)	19.8 (1.0) aA	15.7 (0.9) aB	16.3 (0.9) aA
EverX Flow (EF)	16.3 (1.1) bA	12.1 (0.8) bA	12.3 (0.9) bA
Filteck Fill and Core Flowable Restorative (FF)	11.0 (0.9) cA	10.1 (1.0) cA	10.4 (0.8) cA
SDR Flow+ (SD)	9.2 (0.8) dA	8.2 (1.1) dA	8.4 (1.2) dA
Tetric Evo Flow Bulk Fill (TF)	14.2 (0.9) eA	13.7 (0.8) eA	13.6 (0.9) eA
X-tra Base (XB)	17.3 (0.7) bA	14.4 (0.8) eB	14.2 (0.9) eB

[a] *Values in parenthesis are standard deviations (n=10). The same lowercase letter in the same vertical column indicates no significant difference (p>0.05). The same uppercase letter within an individual row indicates no significant difference (p>0.05).*

microscopy and other devices. In this study, a digimatic micrometer was used to measure cuspal deflection for high- and low-viscosity bulk-fill resins.

Park and others[23] reported results that the cuspal deflection in the layering technique was shown to be considerably lower than that for the bulk-fill technique, and they found no significant difference between horizontal and oblique layering techniques using a conventional resin. However, in that study, the resin used for the bulk-fill technique was a conventional resin with a recommended maximum 2-mm depth of cure. Therefore, the depth of polymerization might not be totally completed in the bulk-fill specimens, making it more difficult to interpret test results. Further, as the bulk-fill technique is not recommended for clinical use with conventional resins, the clinical application of their results may not be applicable.

Recently, high- and low-viscosity bulk-fill resins have been used to expedite the restoration process by

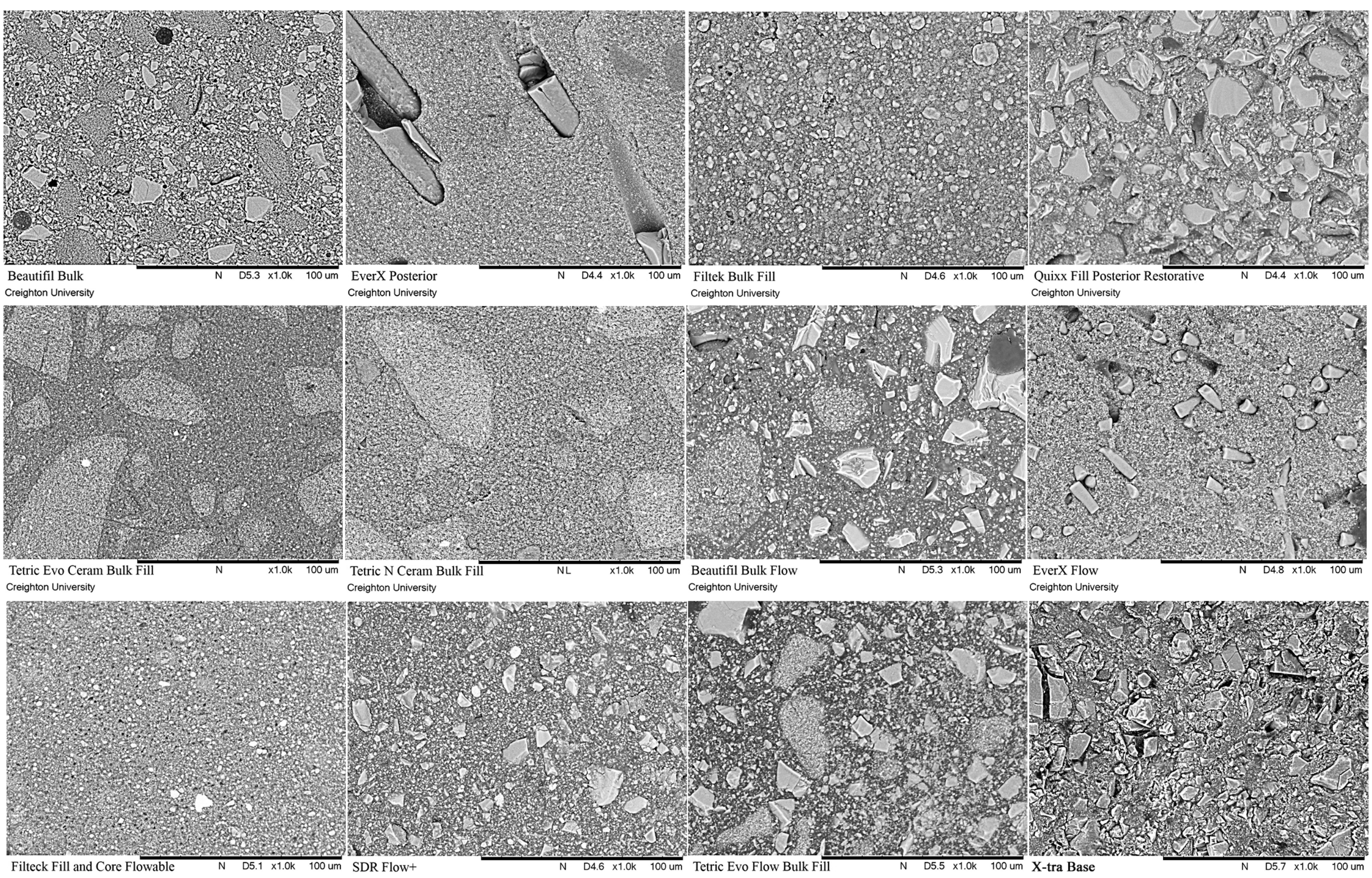

Figure 3. *Scanning electron microscopy observations of the surfaces of high- and low-viscosity bulk-fill resins.*

enabling increments up to 4-mm thick to be light-cured.[19,20] The present study compared the influence of layering techniques on high- and low-viscosity bulk-fill resins. Bulk-fill resins face no problems with polymerization in smaller increments to reduce polymerization shrinkage stress and can be used in bulk-fill or layering techniques in the clinic, as appropriate to the situation. Thus, it is clinically important to determine whether there are reasons to continue to use layering techniques with bulk-fill resins. While Park and others[23] found a significant difference in conventional resin composites, it is not surprising that the present study showed different behavior in cuspal deflection for bulk-fill resins.

The 12 bulk-fill resins used in this study can be classified into four groups according to the level of shrinkage stress produced: 1) high-viscosity bulk-fill resins with low stress (TEB, FB, QP, and TNB); 2) high-viscosity bulk-fill resins with high stress (BB and EP); 3) low-viscosity bulk-fill resins with low stress (SD, FF, and BB); and 4) low-viscosity bulk-fill resins with high stress (BF, EF, and XB). A high-viscosity bulk-fill resin (BB) and a low-viscosity bulk-fill resin (SF) showed the highest and lowest values of cuspal deflections, respectively. Although, within the high- and low-viscosity bulk-fill resins with low stress, there was no significant difference ($p>0.05$) between the value of the cuspal deflection measured with bulk-filling and that measured with layering techniques. For high- and low-viscosity bulk-fill resins with high stress, the difference in cuspal deflection was significant ($p<0.05$). This suggests that, for low shrinkage stress materials, advances in material composition are more important for reducing polymerization shrinkage stress than choice of filling techniques. However, this cannot be said of materials that show high polymerization shrinkage stress.

It is generally accepted that horizontal and oblique layering techniques improve marginal adaptation and bond stability of the adhesive interface between tooth structures and resin.[24] Therefore, when filling a large cavity, the use of small increments horizontally and obliquely was still recommended in one of the reviews[25] so that the polymerization shrinkage stress could be reduced. Although it is true that all the tested materials showed decreased values of cuspal deflection in this study with horizontal and oblique layering techniques, the values did not show statistically significant differences in high- and low-viscosity bulk-fill resins with low stress. Therefore, it appears that the use of polymerization shrinkage reduction technology in resins is more important than layering techniques. This is consistent with recent systematic reviews.[26,27] In those reviews, the technique protocols of placing material no longer showed a great contribution to polymerization shrinkage stress and, indeed, made less difference than the choice of light-curing method. On the other hand, modifying the resin matrix made the largest contribution to minimizing polymerization shrinkage stress development.

The layering technique for composite resins increases treatment time and increases the risk of creating voids and/or other weaknesses within a restoration.[28] Thus, in low polymerization shrinkage bulk-fill resins, the rationale for using layering techniques is diminished because the layering technique has a minimal influence on polymerization shrinkage stress. However, this was not true for all of the bulk-fill resins investigated in the present study; thus, clinicians need to be familiar with the properties of the bulk-fill resin in order to choose the most appropriate procedures. Hayashi and others[29] have shown that bulk-fill resins with higher rates of polymerization shrinkage may nevertheless show much lower gap formation than other resins. This suggests that total polymerization shrinkage and stress are not enough information to guide selection of an appropriate technique, and that detailed information about the interaction between resins and adhesives is necessary. As this information is not easily available outside the research literature, the results of this study suggest that at present it would be safer to continue to use the layering technique as a significant number of bulk-fill resins show significantly higher polymerization shrinkage stress without it. Thus, from the overall results of this study, the null hypothesis that the layering method would have no influence on polymerization shrinkage stress, was rejected for some materials but not for all.

CONCLUSIONS

The results of this study indicate that the effect of layering techniques on polymerization shrinkage stress for high- and low-viscosity bulk-fill resins was material dependent. A decrease in polymerization shrinkage stress with layering techniques was not observed in bulk-fill resins that showed low cuspal deflection (<15 μm).

Acknowledgements

The authors thank Dr Masao Irie of Okayama University and Mr Kazuyoshi Shimizu of 3M Oral Care for comments that greatly improved the manuscript.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

(Accepted 17 February 2020)

REFERENCES

1. Alzraikat H, Burrow MF, Maghaireh GA, & Taha NA (2018) Nanofilled resin composite properties and clinical performance: A review *Operative Dentistry* **43(4)** e173-e190.
2. Miyazaki M, Tsujimoto A, Tsubota K, Takamizawa T, Kurokawa H, & Platt JA. (2014) Important compositional characteristics in the clinical use of adhesive systems *Journal of Oral Science* **56(1)** 1-9.
3. Hosoya Y, Shiraishi T, Odatsu T, Ogata T, Miyazaki M, & Powers JM (2010) Effects of specular component and polishing on color of resin composites *Journal of Oral Science* **52(4)** 599-607.
4. Frencken JE, Peters MC, Manton DJ, Leal SC, Gordan VV, & Eden E (2012) Minimal intervention dentistry for managing dental caries—A review: Report of a FDI task group *International Dental Journal* **62(5)** 223-243.
5. Tsujimoto A, Nagura Y, Barkmeier WW, Watanabe H, Johnson WW, Takamizawa T, Latta MA, & Miyazaki M (2018) Simulated cuspal deflection and flexural properties of high viscosity bulk-fill and conventional resin composites *Journal of the Mechanical Behavior of Biomedical Materials* **87(November)** 111-118.
6. da Veiga AM, Cunha AC, Ferreira DM, da Silva Fidalgo TK, Chianca TK, Reis KR, & Maia LC (2016) Longevity of direct and indirect resin composite restorations in permanent posterior teeth: A systematic review and meta-analysis *Journal of Dentistry* **54** 1-12.
7. Borgia E, Baron R, & Borgia JL (2019) Quality and survival of direct light-activated composite resin restorations in posterior teeth: A 5- to 20-year retrospective longitudinal study *Journal of Prosthodontics* **28(1)** e195-e203.
8. Kopperud SE, Tveit AB, Gaarden T, Sandvik L, & Espelid I (2012) Longevity of posterior dental restorations and reasons for failure. *European Journal of Oral. Sciences* **120(6)** 539-548.
9. Davidson CL & Feilzer AJ (1997) Polymerization shrinkage and polymerization shrinkage stress in polymer-based restoratives *Journal of Dentistry* **25(6)** 435-440.
10. Braga RR, Ballester RY, & Ferracane JL (2005) Factors involved in the development of polymerization shrinkage stress in resin-composites: A systematic review. *Dental Materials* **21(10)** 962-970.
11. Mantri SP & Mantri SS (2013) Management of shrinkage stresses in direct restorative light-cured composites: A review *Journal of Esthetic and Restorative Dentistry* **25(5)** 305-313.
12. Soares CJ, Faria-E-Silva AL, Rodrigues MP, Vilela ABF, Pfeifer CS, Tantbirojn D, & Versluis A (2017) Polymerization shrinkage stress of composite resins and resin cements—What do we need to know? *Brazilian Oral Research* **31(Supplement 1)** e62.
13. Gonçalves F, Kawano Y, & Braga RR (2010) Contraction stress related to composite inorganic content *Dental Materials* **26(7)** 704-709.
14. Satterthwaite JD, Maisuria A, Vogel K, & Watts DC (2012) Effect of resin-composite filler particle size and shape on shrinkage-stress *Dental Materials* **28(6)** 609-614.
15. Braga RR & Ferracane JL (2004) Alternatives in polymerization contraction stress management *Critical Reviews in Oral Biology and Medicine* **15(3)** 176-184.
16. He J, Luo Y, Liu F, & Jia D (2010) Synthesis and characterization of a new trimethacrylate monomer with low polymerization shrinkage and its application in dental restoration materials *Journal of Biomaterials Applications* **25(3)** 235-249.
17. Maghaireh GA, Taha NA, & Alzraikat H (2017) The silorane-based resin composites: A review *Operative Dentistry* **42(1)** e24-e34.
18. Jackson RD & Morgan M (2000) The new posterior resins and a simplified placement technique *Journal of the American Dental Association* **131(3)** 375-383.
19. Tsujimoto A, Barkmeier WW, Takamizawa T, Latta MA, & Miyazaki M (2017) Depth of cure, flexural properties and volumetric shrinkage of low and high viscosity bulk-fill giomers and resin composites *Dental Materials Journal* **36(2)** 205-213.
20. Tsujimoto A, Barkmeier WW, Takamizawa T, Latta MA, & Miyazaki M (2016) Mechanical properties, volumetric shrinkage and depth of cure of short fiber-reinforced resin composite *Dental Materials Journal* **35(3)** 418-424.
21. Cara RR, Fleming GJ, Palin WM, Walmsley AD, & Burke FJ (2007) Cuspal deflection and microleakage in premolar teeth restored with resin-based composites with and without an intermediary flowable layer *Journal of Dentistry* **35(6)** 482-489.
22. Kaisarly D & Gezawi ME (2016) Polymerization shrinkage assessment of dental resin composites: A literature review *Odontology* **104(3)** 257-270.
23. Park J, Chang J, Ferracane J, & Lee IB (2008) How should composite be layered to reduce shrinkage stress: Incremental or bulk filling? *Dental Materials* **24(11)** 1501-1505.
24. Nikolaenko SA, Lohbauer U, Roggendorf M, Petschelt A, Dasch W, & Frankenberger R (2004) Influence of c-factor and layering technique on microtensile bond strength to dentin *Dental Materials* **20(6)** 579-585.
25. Chandrasekhar V, Rudrapati L, Badami V, & Tummala M (2017) Incremental techniques in direct composite restoration *Journal of Conservative Dentistry* **20(6)** 386-391.
26. Münchow EA, Meereis CTW, de Oliveira da Rosa WL, da Silva AF, & Piva E (2018) Polymerization shrinkage stress of resin-based dental materials: A systematic review and meta-analyses of technique protocol and photo-activation strategies *Journal of the Mechanical Behavior of Biomedical Materials* **82(June)** 77-86.

27. Meereis CTW, Münchow EA, de Oliveira da Rosa WL, da Silva AF, & Piva E (2018) Polymerization shrinkage stress of resin-based dental materials: A systematic review and meta-analyses of composition strategies *Journal of the Mechanical Behavior of Biomedical Materials* **82(June)** 268-281.

28. Pardo Díaz CA, Shimokawa C, Sampaio CS, Freitas AZ, & Turbino ML (2020) Characterization and comparative analysis of voids in Class II composite resin restorations by optical coherence tomography *Operative Dentistry* **45(1)** 71-79.

29. Hayashi J, Espigares J, Takagaki T, Shimada Y, Tagami J, Numata T, Chan D, & Sadr A (2019) Real-time in-depth imaging of gap formation in bulk-fill resin composites *Dental Materials* **35(4)** 585-596.